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III-V HETEROJUNCTION STRUCTURES FOR LONG-WAVELENGTH INJECTION LASER

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CW operation of 1.4-μm (micrometer) injection lasers is reported. At 0°C threshold current was 225 mA. A computer-derived table of wavelength vs alloy composition of In GaAsP is presented.

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SECTION I

OBJECTIVE

The long-term objective of our research program is to develop high-quality heterojunction lasers (pulsed and cw), and photodiodes capable of operating at any desired wavelength primarily between 0.92 and at least 1.7 μm, although wavelengths in excess of 2.0 μm should be feasible. In this second phase of our program, the use of vapor-grown quaternary alloys will be evaluated in heteroepitaxial device structures. These structures are comprised of (In,Ga)(As,P) and InP layers deposited primarily onto InP substrates.

SECTION II

PROGRESS

A. CW LASER OPERATION FROM InGaAsP/InP

During the past quarter, efforts to control and optimize the vapor-growth parameters needed to prepare lattice-matched double-heterojunction lasers of InGaAsP/InP have continued. In particular, as indicated in our previous report, the threshold current has been found to depend strongly on cavity thickness, so that improved control of this parameter was required. A smaller temperature gradient has been used for our recent samples, and threshold currents as low as 1700 A/cm^2 have now been obtained.

From one of our low-threshold laser structures, cw operation was obtained at temperatures as high as 15°C, as shown in Fig. 1 for an ambient of 0°C. For these lasers, an oxide-defined stripe-contact geometry was used, which is designed to reduce the effective area of the laser.

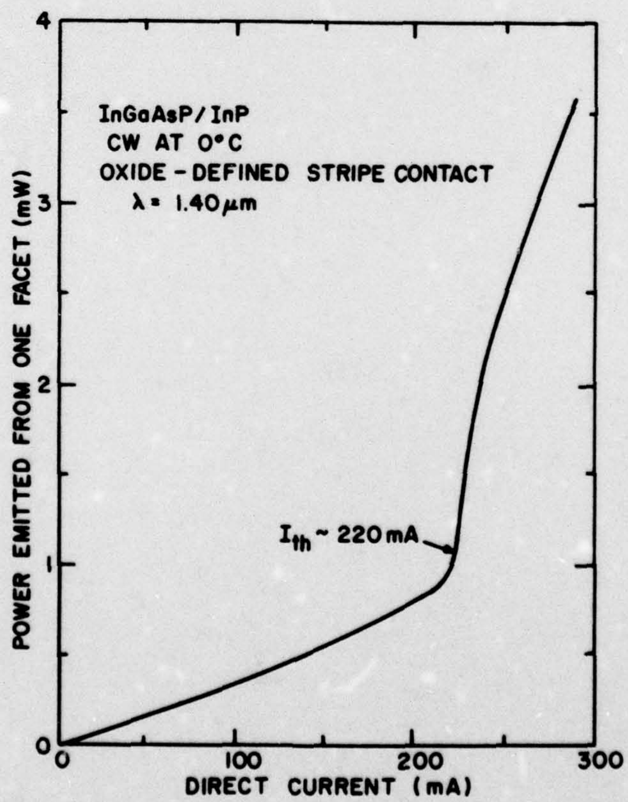

Figure 1. Laser power emission (mW) vs dc applied current (mA) for InGaAsP/InP cw stripe-contact laser at 0°C. CW lasing for this device was obtained up to 15°C.

Although threshold current densities below about 2500 A/cm^2 (the approximate cw threshold) are now being produced with some degree of regularity, we are having an unexpected difficulty achieving cw operation. This may be due to a series resistance problem associated with contacting the p-side of the laser, or to undesirably large current spreading from the stripe. Experiments are presently in progress to improve our technology in both areas.

B. COMPUTER-CALCULATED MATERIAL PARAMETERS FOR (In,Ga)(As,P) ALLOYS

In the Interim Quarterly Report No. 4 of this contract we reported a number of measured lattice parameters and energy-bandgap values for our quaternary materials. These values were shown to be in approximate agreement with values extrapolated from ternary alloys for a series of near-lattice-matched quaternary alloys. Since very little experimental data exists on quaternary alloy material parameters, computer calculations have been made to estimate such values from known binary and ternary data. Methods described by R. L. Moon et al. [1], and T. H. Glisson et al. [2], have been used. Results of the technique are shown in Table I. The room-temperature values of the energy bandgap (E_g), emission wavelength (λ), lattice parameter (a_o), and refractive index (n, at the bandgap emission wavelength) are presented for InGaAsP alloys; also shown are the differences between InP and InGaAsP for the thermal expansion lattice-mismatch (LM-TH), refractive index (Δn), energy bandgap (ΔE_g), and lattice mismatch ($\Delta a_o/a_o$). Other material parameters may be similarly computed, as desired, by programming the particular binary or ternary material constants, when they are known.

The calculated refractive indices in Table I are probably the least reliable of the extrapolated values, since direct measurement of the refractive index is difficult, and ternary experimental data limited. However, the refractive index of InGaAsP can be determined *indirectly* from the half-width ($\theta_\perp$) of the emission far-field pattern in the direction perpendicular to the cavity plane; for this technique, the refractive index of InP is taken to be 3.27, and the relationships between cavity thickness, lasing wavelength, and refractive indices are determined from theoretical waveguide calculations appropriate

1. R. L. Moon et al., J. Electron Mater. **3**, 635 (1974).
2. T. H. Glisson et al., J. Electron Mater. **7**, 1 (1977).

TABLE I. COMPUTER-CALCULATED MATERIAL PARAMETERS FOR InGaAsP ALLOYS

Alloy Composition In	Ga	As	P	E_g (eV)	λ (μm)	a_o (Å)	$\Delta a_o/a_o$ (%)	LM-TH	n	Δn	ΔE_g (eV)
0.55	0.45	0.99	0.01	0.724	1.713	5.8738	0.07	0.07	3.64	0.37	-.626
0.56	0.44	0.97	0.03	0.734	1.689	5.8736	0.07	0.07	3.6[illegible]	0.36	-.616
0.57	0.43	0.94	0.06	0.744	1.666	5.8733	0.07	0.06	3.63	0.36	-.606
0.58	0.42	0.92	0.08	0.755	1.642	5.8731	0.06	0.06	3.62	0.35	-.595
0.59	0.41	0.90	0.10	0.766	1.619	5.8729	0.06	0.06	3.61	0.34	-.584
0.60	0.40	0.88	0.12	0.777	1.596	5.8727	0.06	0.06	3.60	0.3[illegible]	-.573
0.61	0.39	0.86	0.14	0.788	1.574	5.8725	0.05	0.06	3.60	0.33	-.562
0.62	0.38	0.83	0.17	0.799	1.551	5.8723	0.05	0.06	3.59	0.32	-.551
0.63	0.37	0.81	0.19	0.811	1.530	5.8721	0.05	0.05	3.58	0.31	-.539
0.64	0.36	0.79	0.21	0.822	1.508	5.8719	0.04	0.05	3.58	0.31	-.528
0.65	0.35	0.77	0.23	0.834	1.487	5.8718	0.04	0.05	3.57	0.30	-.516
0.66	0.34	0.75	0.25	0.846	1.466	5.8716	0.04	0.05	3.56	0.29	-.504
0.67	0.33	0.73	0.27	0.858	1.445	5.8714	0.03	0.05	3.55	0.28	-.492
0.68	0.32	0.70	0.30	0.870	1.425	5.8713	0.03	0.05	3.55	0.28	-.480
0.69	0.31	0.68	0.32	0.883	1.405	5.8711	0.03	0.05	3.54	0.27	-.467
0.70	0.30	0.66	0.34	0.895	1.385	5.8710	0.03	0.04	3.53	0.26	-.455
0.71	0.29	0.64	0.36	0.908	1.366	5.8708	0.02	0.04	3.52	0.25	-.442
0.72	0.28	0.62	0.38	0.921	1.347	5.8707	0.02	0.04	3.51	0.24	-.429
0.73	0.27	0.59	0.41	0.934	1.328	5.8706	0.02	0.04	3.51	0.24	-.416
0.74	0.26	0.57	0.43	0.947	1.309	5.8704	0.02	0.04	3.50	0.23	-.403
0.75	0.25	0.55	0.45	0.960	1.291	5.8703	0.02	0.04	3.49	0.22	-.390
0.76	0.24	0.53	0.47	0.974	1.273	5.8702	0.01	0.03	3.48	0.21	-.376
0.77	0.23	0.51	0.49	0.988	1.256	5.8701	0.01	0.03	3.47	0.20	-.362
0.78	0.22	0.48	0.52	1.001	1.238	5.8700	0.01	0.03	3.47	0.20	-.349
0.79	0.21	0.46	0.54	1.016	1.221	5.8699	0.01	0.03	3.46	0.19	-.334
0.80	0.20	0.44	0.56	1.030	1.204	5.8698	0.01	0.03	3.45	0.18	-.320
0.81	0.19	0.42	0.58	1.044	1.188	5.8698	0.01	0.03	3.44	0.17	-.306
0.82	0.18	0.40	0.60	1.059	1.171	5.8697	0.00	0.03	3.43	0.16	-.291
0.83	0.17	0.37	0.63	1.073	1.155	5.8696	0.00	0.02	3.42	0.15	-.277
0.84	0.16	0.35	0.65	1.088	1.139	5.8696	0.00	0.02	3.42	0.15	-.262
0.85	0.15	0.33	0.67	1.103	1.124	5.8695	0.00	0.02	3.41	0.14	-.247
0.86	0.14	0.31	0.69	1.119	1.109	5.8695	0.00	0.02	3.40	0.13	-.231
0.87	0.13	0.29	0.71	1.134	1.094	5.8694	0.00	0.02	3.39	0.12	-.216
0.88	0.12	0.26	0.74	1.149	1.079	5.8694	0.00	0.02	3.38	0.11	-.201
0.89	0.11	0.24	0.76	1.165	1.064	5.8693	0.00	0.02	3.37	0.10	-.185
0.90	0.10	0.22	0.78	1.181	1.050	5.8693	0.00	0.01	3.36	0.09	-.169
0.91	0.09	0.20	0.80	1.197	1.036	5.8693	0.00	0.01	3.35	0.08	-.153
0.92	0.08	0.18	0.82	1.214	1.022	5.8693	0.00	0.01	3.35	0.08	-.136
0.93	0.07	0.15	0.85	1.230	1.008	5.8693	0.00	0.01	3.34	0.07	-.120
0.94	0.06	0.13	0.87	1.247	0.995	5.8693	0.00	0.01	3.33	0.06	-.103
0.95	0.05	0.11	0.89	1.263	0.982	5.8693	0.00	0.01	3.32	0.05	-.087
0.96	0.04	0.09	0.91	1.280	0.968	5.8693	0.00	0.01	3.31	0.04	-.070
0.97	0.03	0.07	0.93	1.297	0.956	5.8693	0.00	0.00	3.30	0.03	-.053
0.98	0.02	0.04	0.96	1.315	0.943	5.8693	0.00	0.00	3.29	0.02	-.035
0.99	0.01	0.02	0.98	1.332	0.931	5.8694	0.00	0.00	3.28	0.01	-.018
1.00	0.00	0.00	1.00	1.350	0.919	5.8694	0.0	0.0	3.27	0.0	-.000

to double-heterojunction lasers [3]. This analysis has been found to describe closely the measured far-field patterns of AlGaAs lasers. In Table II, we summarize values of Δn, the refractive index step, determined from far-field patterns of our InGaAsP/InP lasers; also shown are values of Δn predicted from our computer interpolation of material constants from binary and ternary III-Vs. The general agreement between the values of Δn determined by the two techniques is reasonable. Thus, *indirectly measured* values of refractive index steps can be estimated from extrapolation of binary data.

TABLE II. MEASURED (FAR-FIELD) AND CALCULATED VALUES OF THE REFRACTIVE INDEX STEP FOR InGaAsP/InP

Laser #	d_3 (μm)	λ (μm)	$\theta_\perp$ (°)	Δn (far-field)	Δn (calculated)
F755	0.60	1.12	46	0.14	0.14
1946	0.15	1.12	40	0.20	0.14
2057	0.20	1.12	37	0.16	0.14

Note also, from Table II, that the refractive index step near 1.12 μm is quite small (0.14–0.18), requiring a wider recombination region to confine effectively the laser radiation. For example, at 1.12 μm a cavity thickness as large as 0.45 μm is required to confine 80% of the radiation to the cavity. This suggests that short-wavelength quaternary lasers ($1.05 < \lambda < 1.15$ μm) will have increased threshold currents due to either: (i) loss of confinement for very thin laser cavities, or (ii) reduced carrier injection as a result of widening the cavity to achieve confinement. The optimum thickness in the range of 0.1–0.4 μm will have to be determined empirically.

C. INITIAL STABILITY OF ELECTROLUMINESCENCE EMISSION

Initial lifetest data indicates that our vapor-grown quaternary InGaAsP/InP laser structures have more uniform operating life characteristics and less

3. H. Kressel and J. K. Butler, *Semiconductor Lasers and Heterojunction LEDs* (Academic Press, New York, 1977) p. 214.

degradation than ternary InGaAs/InGaP lasers. Lifetests are presently being carried out on these devices under a U.S. Army Electronics Command Contract (DAAB07-77-C-2173). The improved reliability (over ternary structures) is attributed to the lack of lattice mismatch ($\Delta a/a \simeq 0$) and small ($\sim 2 \times 10^{-4}$) thermal expansion differences between the InGaAsP and InP layers, as indicated in Table I for wavelengths between 1.05 and 1.2 µm.

REFERENCES

1. R. L. Moon et al., J. Electron Mater. 3, 635 (1974).
2. T. H. Glisson et al., J. Electron Mater. 7, 1 (1977).
3. H. Kressel and J. K. Butler, *Semiconductor Lasers and Heterojunction LEDs* (Academic Press, New York, 1977) p. 214.